EFFECTS OF CURING REGIME AND BINDERS ON POLYMERIC CONCRETE

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Effects of Curing Regime and Binders on Polymeric Concrete

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CERTIFICATION OF APPROVAL

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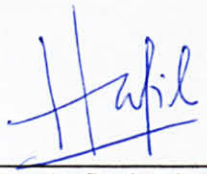
CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.



(Nor Hafizah Binti Tajudin)

ABSTRACT

This report will generally discuss on the progress and basic understanding on selected Final Year Project (FYP) title which is Effects of Curing Regime and Binders on Polymeric Concrete. Portland cement concrete has been widely used as construction materials. However, the impact of cement production on environment has become one of the most challenging issues. Therefore, it is essential to introduce new technologies and practices for alternative cement in order to curtail the rising CO_2 emissions caused by increased Portland cement production and solve serious disposal problems of by-product materials such as fly ash, silica fume and rice husk ash. Furthermore, this new technology will slow down the depletion of raw material mainly limestone used for cement production. This research has been conducted to determine the optimum mix proportion of polymeric concrete incorporating fly ash, MIRHA and silica fume. Besides, in order to get a standard curing method in cast in situ polymeric concrete, this research used different curing regime namely hot gunny, ambient and external exposure curing and focused on determining the compressive strength, flexural strength and tensile strength.

This research utilized low-calcium (ASTM Class F) fly ash, MIRHA and silica fume as the source materials in producing polymeric concrete. While for the alkaline solution, this research utilized sodium hydroxide, NaOH and sodium silicate, Na_2SiO_3. As the outcome of this research, it can be concluded that fly ash, MIRHA and silica fume together with alkaline solution (Sodium Hydroxide, NaOH and Sodium Silicate, Na_2SiO_3) can be a good replacement of cement in concrete and external exposure curing is the best curing regime for cast in situ polymeric concrete.

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CHAPTER 1

1.1 INTRODUCTION

Portland cement concrete has been widely used as construction materials. Increasing demand of concrete as construction materials will also increase the demand for Portland cement. It is estimated that the production of cement will increase from about from 1.5 billion tons in 1995 to 2.2 billion tons by 2010 (Malhotra, 1999).

Therefore, the impact of cement production on environment has become one of the most challenging issues. This is because global warming has become a major concern due to the increase problems of climate change. The global warming is caused by the emission of greenhouse gases, such as carbon dioxide (CO_2) to the atmosphere by human activities. Among the greenhouse gases, CO_2 contributes about 65% of global warming (McCaffrey, 2002). The cement industry is held conscientious for some of the CO_2 emissions, because the production of one ton of Portland cement emits approximately one tonne of CO_2 into the atmosphere (McCaffrey, 2002 & Davidovits, 1994).

Several efforts are taken to reduce the use of Portland cement in concrete to address the global warming issues. These include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast-furnace slag, rice-husk ash, and metakaolin, together with the development of alternative binders to Portland cement (Rangan, 2008).

1.2 BACKGROUND STUDY

Geopolymer technology proposed by Davidovits (1988) shows that it can be applied in concrete industry as an alternative binder to the Portland cement. This technology could reduce up to 80% CO_2 emissions to the atmosphere caused by the cement and aggregates industries (Davidovits, 1994).

Davidovits (1988, 1994) proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in by-product materials such as fly ash and rice husk ash to produce binders. The chemical reaction that takes place in this case is a polymerization process whereby the term 'Geopolymer' is used to represent these binders.

The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. Geopolymers is an inorganic polymer. The polymerization process involves a fast chemical reaction under alkaline condition on Si-Al minerals, which result in a three-dimensional polymeric chain and ring structure consisting of Si-OAl-O bonds (Davidovits, 1994).

The schematic formation of geopolymer material can be shown as described by Equations (1) and (2) (Davidovits, 1994; Van Jaarsvels et al, 1997):

$$n(Si_2O_5,Al_2O_2)+2nSiO_2+4nH_2O+NaOH \text{ or } KOH \rightarrow Na^{+},K^{+} + n(OH)_3\text{-Si-O-Al}^{-}\text{-O-Si-}(OH)_3$$

(Si-Al materials)

$(OH)_2$

(Geopolymer precursor) (1)

$$n(OH)_3\text{-Si-O-Al}^{-}\text{-O-Si-}(OH)_3 + NaOH \text{ or } KOH \rightarrow (Na^{+},K^{+})\text{-(-Si-O-Al}^{-}\text{-O-Si-O-)} + 4nH_2O$$

$(OH)_2$ O O O

(Geopolymer backbone) (2)

The last term in Equation 2 reveals that water is released during the chemical reaction that occurs in the formation of geopolymers. This water, expelled from the geopolymer matrix during the curing and further drying periods, leaves behind discontinuous nano-pores in the matrix, which provide benefits to the performance of geopolymers (Davidovits, 1994; Van Jaarsvels et al, 1997).

The water in a geopolymer mixture, do not involve in the chemical reaction, this is because water provides the workability to the mixture during handling. This is in contrast to the chemical reaction of water in a Portland cement concrete mixture during the hydration process (Davidovits, 1994; Van Jaarsvels et al, 1997).

Two main constituents of geopolymers are the source materials and the alkaline liquids. The source materials for geopolymers based on alumina-silicate should be rich in silicon (Si) and aluminium (Al). These could be natural minerals such as kaolinite, clays, etc. Alternatively, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc could be used as source materials (Davidovits, 1994; Van Jaarsvels et al, 1997).

Source materials for making geopolymers should be chosen depend on factors such as type of application, availability and specific demand of the end users and cost. The alkaline liquids are from soluble alkali metals that are usually Sodium or Potassium based. The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate (Davidovits, 1994; Van Jaarsvels et al, 1997).

1.3 PROBLEM STATEMENT

Ordinary Portland cement (OPC) is usually used as the primary binder to produce concrete. However, OPC impacts to the environment are well known. It is estimated that the production of 1 tonne of OPC due to the calcinations of limestone and combustion of fossil fuel results in the emission of 1 tonne of carbon dioxide (CO_2) gases, a major contributor to greenhouse effect and global warming.

Therefore, it is essential to introduce new technologies and practices for alternative cement in order to curtail the rising CO_2 emissions caused by increased Portland cement production and solve serious disposal problems of by product materials such as fly ash, silica fume and MIRHA. Furthermore, these new technologies will slow down the depletion of raw material (mainly limestone) used for cement production.

Polymeric concrete that utilize by product materials namely fly ash, silica fume and MIRHA eliminates completely OPC concrete is expected to solve this problem.

Besides, other potential benefits of using larger amounts of by product materials in concrete including reduced landfills, lower-cost concrete whereby, increased durability, and reduced disposal costs.

Currently, research that has been done on fly ash based polymeric concrete is for precast concrete. Therefore, this research is conducted into blended polymeric using fly ash, Microwave Incinerated Rice Husk Ash (MIRHA) and silica fume as the source material. In order to get a standard in cast in situ polymeric concrete, this research used different curing regime namely hot gunny, ambient and external exposure curing and focused on its compressive strength, flexural strength and tensile strength.

1.4 OBJECTIVES

a) To determine the optimum mix proportion of polymeric concrete incorporating fly ash, MIRHA and silica fume.
b) To ascertain the suitable curing regime for cast in situ polymeric concrete.
c) To determine the compressive, tensile and flexural strength of polymeric concrete.

1.5 SCOPE OF STUDY

The research utilized low-calcium (ASTM Class F) fly ash, MIRHA and silica fume as the source material in producing polymeric concrete. The concrete properties studied were compressive strength, tensile strength, flexural strengths of the hardened concrete and the workability of fresh concrete. Three types of curing regime that has been studied are hot gunny, ambient and external exposure curing.

Four different mix designs were investigated for each type of curing regime. Concrete samples were designed with two conditions, blended and non blended source materials. Non-blended source material only has fly ash as the source material while blended source material consists of fly ash-silica fume and fly ash-MIRHA. Each mix design will have same percentage of fine aggregates, coarse aggregates, sodium hydroxide solution, sodium silicate solution, sugar and additional water.

CHAPTER 2
LITERATURE REVIEW

2.1 BY-PRODUCT MATERIALS USED IN CONCRETE MANUFACTURING

Silica fume is also referred to as microsilica or condensed silica fume. Silica fume is a by-product of silicon metal or silicon alloymetal factories. Silica fume is the most valuable by-product between the pozzolanic materials because it has high pozzolanic property and very active. Currently, silica fume is normally used as cement replacing materials (Erdogan, 2003). Silica fume is a highly reactive pozzolan because of the 3 characteristics (ACI, 1994).

i. an average particle diameter of 0.1 mm (approximately 100 times smaller than average Portland cement particles)
ii. a high amorphous silica composition (typically >90% SiO2)
iii. a very high surface area of 20,000 m2/kg (as compared to Portland cement values of 300–500 m2/kg).

It is called silica fume because the escaping gaseous SiO oxidizes and condensates in the form of extremely fine spherical particles or amorphous silica (SiO_2). Silica in the form of glass (amorphous) is highly reactive and the smallness of the particles speeds up the reaction with calcium hydroxide (NaOH) produced by the hydration process. When the furnace has an efficient heat recovery system, most of the carbon is burnt so that silica fume is virtually free from carbon and is light in colour. Furnaces without a full heat recovery system leave some carbon in the fume which is therefore dark in colour (Neville, 1995).

In terms of curing, it is shown that curing conditions will give affect on hydration and pozzolanic reaction. Therefore, it is expected that curing conditions influence the strength of silica fume concrete. Aitcin et al. (1985) stated that dry curing regimes gives greater effect on strength of silica fume compared to Portland cement.

Remezaniapour and Malhotra (1995) reported that compressive strength of silica fume concrete will drop 28% due to dry curing. However, Mazloom et. al. (2004) reported the opposite. They reported that moist curing did not have any significant effects on sample containing silica fume although moist curing had given significant impact on control concrete.

There is inconsistency between the researches regarding the influence of curing regime on concrete incorporating silica fume. Therefore, the effect of different curing regime on silica fume concrete or concrete incorporating other pozzolan materials such as fly ash and MIRHA needs more research.

Fly ash are finely divided residue resulting from the combustion of ground or powdered coal and consists mainly of SiO_2, $Al2O_3$, Fe_2O_3, and CaO and some impurities. They are generally finer than cement and consist mainly of glassy-spherical particles as well as residues of hematite and magnetite, char, and some crystalline phases formed during cooling.

According to ASTM C618, fly ash belongs to Class F if $(SiO_2 + Al_2O_3 + Fe_2O_3) > 70\%$, and belongs to Class C if $70\% > (SiO_2 + Al_2O_3 + Fe_2O_3) > 50\%$. Usually, Class F fly ashes have a low content of CaO and exhibit pozzolanic properties, but Class C fly ashes contain up to 20% CaO and exhibit cementitious properties. The use of cement in concrete can be replaced by this pozzolanic material which is obtained from by product materials from industrial and agricultural industry.

Rennes (1999) investigated the origin of pozzolanic effects of rice husk ash and claimed that its presence in the ash is because of the amorphous silica that can be found in the rice

husk (Jauberthie et. al, 2000). It has been proved that rice husk ash contain amorphous silica which can be used to increase the effects of durability in concrete (Spire et. al., 1999). Tamba et. al. (2000) reported that rice husk is used to produce light weight concrete .It can improve the tensile strength on concrete.

2.2 CEMENT REPLACEMENT MATERIALS

2.2.1 Fly Ash

Ordinary Portland Cement can be totally replaced by the geopolymer concrete incorporating source materials like fly ash. Therefore, the use of geopolymer technology not only substantially reduces the CO_2 emissions by the cement industries, but also utilises the waste materials such as fly ash. It is to be noted that fly ash is available abundantly world wide, and yet its usage to date is very limited (Malhotra; 1999, 2002a, 2002b).

Lately, a lot of researches have been conducted to prove the potential use of fly ash-based geopolymer in cement and concrete production. Geopolymers has been shown to have good bond strength and good in abrasion resistance. Besides, fly ash based polymeric concrete also has shown good performance in resistance to sulfate attacks, has lower creep and shrinkage compared to OPC.

2.2.2 Silica Fume

Several researches reported that the behavior of silica fume in concrete is physiochemical. The physical phase is in the refinement of the void system of cement paste and particularly the transition zone. The chemical phase consists of the pozzolanic reaction that transforms the weak calcium hydroxide crystals into the strong calcium silicate hydrate gel. The results of these actions of silica fume provide large improvements in compressive and flexural strengths along with improvement in

durability and impermeability (Ozturan,1993; Mehta, 1998; Toutanji, 1999; Messaza,2000).

Regarding the influence of flexural strength, Khedr and Abou-Zeid (1994) found that silica fume concrete increases flexural strength up to 20% to 33% with 15 % and 20 % silica fume at 28 days age of concrete.
In terms of effects of tensile strength, Hooton (1993) reported that the tensile strength of concrete with 15% and 20% silica fume exhibited a reduction in strength by 9.7% and 21%, respectively. Besides, the addition of silica fume reduces the splitting tensile strength of concrete at an age of 91 days.

The use of silica fume in concrete increases the resistance of concrete to acid and sulfate attack. Besides, it improves durability of concrete by reducing porosity and permeability of cement paste matrix (Erdogan, 2003; Akoz et. al., 1995, 1997, 1999) In addition, it makes the concrete more resistant to abrasive forces and reduces the expansion generated by alkali-aggregate expansion (Mehta, 1985).

2.2.3 Rice Husk Ash

Rice husk ash (RHA) is obtained from combustion of rice husk. Large amount of rice husks has been produced annually in the entire world. Based on International Rice Research Institute (2008), world rice production in 2008 already exceeds 700 million tonnes per year. This creates a big problem in order to dispose its husk. This problem enhances many researchers to find solution for this problem.

CHAPTER 3
METHODOLOGY

3.1 MATERIALS SELECTION

3.1.1 Fly Ash

Fly ash produced by Manjung Power Station, Malaysia was used as the alumino-silicate material in this research. The Chemical Properties of Fly Ash are presented in Table 3.1.

Table 3.1: Chemical Properties of Fly Ash

Compounds	Percentages (%)
SiO_2	51.19
Al_2O_3	24
Fe_2O_3	6.6
CaO	5.57
MgO	2.4
SO_3	0.88
K_2O	1.14
Na_2O	2.12

3.1.2 Microwave Incinerated Rice Husk Ash (MIRHA)

3.1.2.1 Burning procedure

In this research, the author used high temperature microwave incinerator to produce MIRHA. Figure 3.1 shows the rice husk ash while Figure 3.2 shows the microwave incinerator equipment used in this research.

Figure 3.1: Rice Husk

Figure 3.2: Microwave Incinerator

The temperature used to burn the rice husk is 800 °C. Figure 3.3 shows the rice husk ash after burning process. It is called MIRHA (Microwave Incinerated Rice Husk Ash).

Figure 3.3: MIRHA after burning

In order to achieve higher reactivity of MIRHA, it must have fine particle size and high surface area. Therefore, MIRHA need to be ground. The machine used to grind the MIRHA is Los Angeles (LA) Abrasion machine. Figure 3.4 shows the LA Abrasion machine and Figure 3.5 shows MIRHA after grinding.

Figure 3.4: Los Angeles Abrasion Machine

Figure 3.5: MIRHA

3.1.3 Silica Fume

Silica fume was supplied by Elkem Materials. The purity of silica fume is 98%. Figure 3.6 below shows silica fume used in this research.

Figure 3.6: Silica Fume

Table 3.2 below shows the Chemical Composition of Ordinary Portland Cement, Silica Fume and MIRHA.

Table 3.2: Chemical Composition of Ordinary Portland Cement, Silica Fume and MIRHA

Chemical Composition	Ordinary Portland Cement (%)	Silica Fume (%)	MIRHA (%)
SiO_2	20.449	96.355	90.75
Al_2O_3	2.8357	0.21	0.7539
Fe_2O_3	4.6352	0.7701	0.7227
CaO	67.7341	0.2396	0.8676
MgO	1.4334	0.5196	0.6287
SO_3	2.202	0.5504	0.3328
K_2O	0.2646	1.018	3.7675
Na_2O	0.0164	0.1186	0.0218
P2O5	0.1023	0.1287	2.5049
ZnO	-	-	-
Cl-	-	-	-

3.1.4 Alkaline Solution

The alkaline solutions in solution used in this research are sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). Alkaline liquid was used to react with the silicon (Si) and the aluminium (Al) in fly ash, rice husk ash and silica fume to produce binders (Davidovits; 1988, 1994). Figure 3.6 shows the Natrium hydroxide (NaOH) pellet used in this research while Figure 3.7 and 3.8 shows the Sodium Hydroxide and Sodium Silicate solution.

Figure 3.7: Sodium Hydroxide Solution (NaOH)

Figure 3.8: Sodium Silicate Solution (Na_2SiO_3)

3.1.4.1 Preparations of Alkaline Solution

Sodium hydroxide (NaOH) was used in form of pellets. Concentration of solution was 8M and in order to make 1 Kg of solution 29.4% of pellets were added to the water. Sodium silicate (Na_2SiO_3) was used in a solution form with mixture composition 56.31% of water, 29.43% of SiO_2 and 14.26% of Na_2O. The sodium hydroxide (NaOH) was dissolved in water to make the solution with the required concentration.

3.1.5 Aggregate

The fine and coarse aggregates were local natural sand and gravel, respectively. Size of coarse aggregates used in this research are 20mm while size of fine aggregates are 5 mm. Coarse aggregates were in saturated-surface-dry (SSD) condition.

3.1.6 Sugar

Sugar was used as a retarder in this research was taken form Perlis, Malaysia. Sugar has been added to delay setting time of polymeric concrete. Therefore, fresh polymeric concrete took longer time to harden so that it will be easier to handle and cast. Besides, the purpose of adding sugar is to increase water viscosity so that it is not easily evaporated. When water is not easily evaporated, it can prevent pre-matured crack cause by shrinkage due to high temperature during curing exposure to occur in the polymeric concrete. Figure 3.9 shows sugar that has been used in this research.

Figure 3.9: Sugar

3.1.7 Water

Water was added to the mixture to improve the workability of the concrete. Water used in the mixture should not contain undesirable organic substances or inorganic constituents in excessive proportions. This is because impurities in water may interfere with the setting of the cement, may adversely affect the strength of the concrete or cause staining of its surface (Neville, 1995).

3.2 CONCRETE MIXING, CASTING AND COMPACTING

B.V. Rangan (2008) reported that polymeric concrete can be manufactured by adopting the conventional techniques in the manufacture of Portland cement concrete. The procedure of the machine mixing that has been used in this research was conducted to establish the standard of mixing for polymeric concrete. In the laboratory, the source materials and the aggregates were mixed together in the concrete mixer for about 150 seconds. The alkaline liquid, sugar solution and additional water were added to the dry materials in the concrete mixer. The mixing is continued for another 90 seconds. Figure 3.10 shows concrete mixer used in this research. Figure 3.11 shows Polymeric Concrete during Mixing Process.

Figure 3.10: Concrete Mixer

Figure 3.11: Polymeric Concrete during Mixing Process

After mixing, fresh polymeric concrete mixture was hand-mixed to ensure the homogeneity of the polymeric concrete. The mixture was then taken for workability test by conducting slump test. After that, the concrete mixture was casted in 100x100x500mm beams for flexural strength test, 200x100mm cylinders for tensile strength test and 100mmx100mmx100mm cubes for compressive strength test. Figure 3.12 shows the Polymeric Concrete Casting.

Figure 3.12: Polymeric Concrete Casting

The moulds surface was greased with mineral oil in order to prevent the development of bond between the mould and the concrete. Fresh concrete was casted in 3 layers in the mould and compacted by using poker vibrator. When concrete is vibrated, the internal friction between the aggregate particles is temporarily destroyed and the concrete behave like a liquid; it settles in the forms under the action of gravity and the large entrapped air voids rise more easily to the surface. Internal friction is reestablished as soon as vibration stops. After that, the moulded specimens will be left outside the laboratory for 24 hours and then demoulded and moved into specified area to undergo curing process. Three types of curing regime that has been used in this research are hot gunny, ambient and external exposure curing until they were taken for testing. Table 3.3 shows Mixture proportion of Polymeric Concrete.

Table 3.3: Mixture Proportions of Polymeric Concrete

Code	Curing Regime	Fly Ash	MIRHA	Silica Fume	CA	FA	NaOH	Na_2SiO_3	Sugar	Extra Water
		(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(%)	(%)
A1	Hot Gunny	350	0	0	1200	645	41	103	3	10
A2		339.5	10.5	0	1200	645	41	103	3	10
A3		332.5	17.5	0	1200	645	41	103	3	10
A4		325.5	24.5	0	1200	645	41	103	3	10
AS2		339.5	0	10.5	1200	645	41	103	3	10
AS3		332.5	0	17.5	1200	645	41	103	3	10
AS4		325.5	0	24.5	1200	645	41	103	3	10
B1	Ambient	350	0	0	1200	645	41	103	3	10
B2		339.5	10.5	0	1200	645	41	103	3	10
B3		332.5	17.5	0	1200	645	41	103	3	10
B4		325.5	24.5	0	1200	645	41	103	3	10
BS2		339.5	0	10.5	1200	645	41	103	3	10
BS3		332.5	0	17.5	1200	645	41	103	3	10
BS4		325.5	0	24.5	1200	645	41	103	3	10
C1	External Exposure	350	0	0	1200	645	41	103	3	10
C2		339.5	10.5	0	1200	645	41	103	3	10
C3		332.5	17.5	0	1200	645	41	103	3	10
C4		325.5	24.5	0	1200	645	41	103	3	10
CS2		339.5	0	10.5	1200	645	41	103	3	10
CS3		332.5	0	17.5	1200	645	41	103	3	10
CS4		325.5	0	24.5	1200	645	41	103	3	10

3.3 CURING OF POLYMERIC CONCRETE

There are 3 types of curing regime that has been conducted in this research which were hot gunny, ambient and external exposure curing.

For external exposure curing, the temperature range is 33-40°C while for the ambient curing the temperature is 27-32°C. However, in the hot gunny curing, the temperature for early 2 days is 80°C and after the plastic sheet is removed, the temperature will drop to atmosphere temperature.

In hot gunny curing, hardened polymeric concrete sample after demoulding process was applied with wet hot gunny on top of it. Plastic sheet has been used to cover the concrete sample to prevent heat being released immediately. This process has been done for two days after concrete sample has been demoulded. Figure 3.13 illustrations on external hot gunny curing.

Figure 3.13: Hot gunny curing

In ambient curing, concrete sample was placed in shaded area that was protected from rain and sunlight but still receives temperature from outside environment as illustrated in Figure 3.14.

Figure 3.14: Ambient curing

External exposure curing was conducted by placing concrete sample in a chamber. The chamber allow sunlight to penetrate while protect the samples from rain as shown in Figure 3.15.

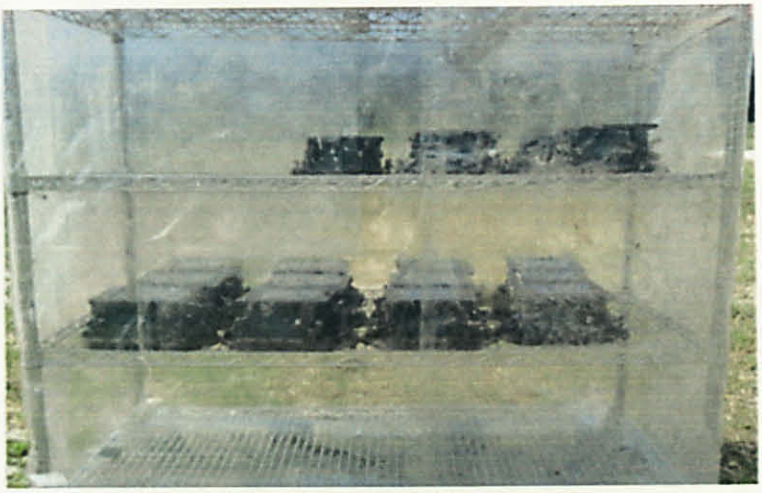

Figure 3.15: External Exposure Curing

3.4 CONCRETE TESTING

Testing for concrete specimen was conducted for fresh concrete and hardened concrete. The workability of fresh concrete was determined by conducting slump test. The hardened concrete was tested by conducting compressive strength test, flexural strength test and tensile test.

3.4.1 Slump Test

Slump test was conducted to determine the workability of the fresh concrete. Slump test in this research was conducted according to BS EN 12350-2:2000. The mould for the slump test is a frustum of a cone with 300mm height. Before conducting the slump test, the internal surface of the cone and its base should be washed to reduce the influence of surface friction on the slump result. The slump cone is placed on a smooth surface with the smaller opening at the top and filled with concrete in 3 layers. Each layer is tamped 25 times with a standard 16mm diameter steel rod, rounded at the end. After the last layer has been tamped, the top surface is struck off by means of rolling motion of the tamping rod. Immediately after shredding, the cone was slowly lifted and the unsupported concrete would slump down. The decrease in the height of the slumped concrete is called slump and is measured to the nearest 5mm. Figure 3.16 shows the Slump Test.

Figure 3.16: Slump Test

3.4.2 Compressive Strength Test

Compressive strength of the concrete was determined by conducting the compressive strength according to BS EN 12390-3:2002 by using Compressive Testing Machine. The measurement is taken for 3 samples per mix at age 3, 7 and 28 days. 100x100x100 mm cube sizes were used for this research. Compressive strength can be determined by using the following formula:

$$F = P / A$$

Where F: Compressive strength (N/mm^2)

P: Ultimate load (kN)

A: Applied load surface area ($mm^{2)}$

Figure 3.17 shows Compressive Testing Machine which has been used to conduct compressive test on 100mmx100mmx100mm polymeric concrete cubes.

Figure 3.17: Compressive Testing Machine

3.4.3 Flexural Strength Test

Flexural strength of the concrete in determined by conducting flexural strength test according to BS EN 12390-5:2009 using Compressive Testing Machine. In this test, an unreinforced concrete beam is subjected to flexure using symmetrical 3-point loading until failure occurs. The measurement was taken for 1 concrete beam per mix at ages 28 days. The concrete beams size used in this research were 100mmx100mmx500mm. The theoretical maximum tensile stress reached at the bottom fiber of the test beam is known as the modulus of rupture. If fracture occurs within the central one-third of the beam, the modulus of rupture is calculated on the basis of ordinary elastic theory and thus equal to:

$$PL / (bd^2),$$

Where P: Maximum load on the beam

L: Span

b: Width of the beam

d: Depth of the beam

Figure 3.18 illustrates beam undergo Flexural Test.

Figure 3.18: Flexural Test

3.4.4 Indirect Tensile Strength Test

The tensile strength of the polymeric concrete incorporating fly ash, MIRHA and silica fume was measured by performing the cylinder splitting test according to BS EN 12390-6: 2000 by using Compressive Testing Machine. The measurement was taken for 2 concrete cylinders at ages 28 days. The concrete cylinders size used in this research were 100mmx200mm. Figure 3.19 shows sample of polymeric concrete after undergo tensile test at 28 days.

Figure 3.19: Polymeric Concrete after undergo Tensile Test

Table 3.4: The Experiment Detail for Concrete Specimen Test

Concrete Type	Test Type	Standard	Equipment	Testing Age	Sample Size	Number of Test	Measurement Unit
FRESH CONCRETE	Slump Test	BS EN 12350-2 : 2000	Slump Cone	Fresh Concrete	-	Each batch	mm
HARDENED CONCRETE (Destructive Test)	Compression Strength	BS EN 12390-3: 2002	Compression Testing Machine	3,7 and 28days	100mmx 100mmx 100mm cube	3 cubes / mix / age	N/mm^2
	Flexural Strength	BS EN 12390-5 : 2009	Compression Testing Machine	28 days	100mmx 100mmx 500mm beam	1 beam / mix / age	N/mm^2
	Tensile Strength	BS EN 12390-6 : 2000	Compression Testing Machine	28 days	100mmx 200mm cylinder	2 cylinders / mix / age	N/mm^2

CHAPTER 4

RESULTS AND DISCUSSION

This chapter contains results that has been obtained for fresh concrete test and hardened concrete test. Workability of every fresh concrete sample has been tested by using slump test. While compressive strength test, flexural strength test and tensile test has been done for the hardened concrete.

4.1 Properties of Fresh Concrete

A property of fresh concrete that has been measured in this research is the workability of the fresh concrete. Table 4.1 and Table 4.2 show the workability characteristics obtained from the slump test for each Fly Ash-Silica Fume and Fly Ash-MIRHA concrete mixture respectively.

Table 4.1: Workability Characteristics for Fly Ash-Silica Fume Mix Proportion

Curing Regime	Mix Code	Silica Fume (%)	Slump (mm)
Hot Gunny	A1	0	240
	AS2	3	220
	AS3	5	215
	AS4	7	200
Ambient	B1	0	230
	BS2	3	230
	BS3	5	230
	BS4	7	220
External Exposure	C1	0	240
	CS2	3	235
	CS3	5	235
	CS4	7	220

Table 4.2: Workability Characteristics for Fly Ash-MIRHA Mix Proportion

Curing Regime	Mix Code	MIRHA (%)	Slump (mm)
Hot Gunny	A1	0	240
	A2	3	235
	A3	5	210
	A4	7	170
Ambient	B1	0	230
	B2	3	225
	B3	5	215
	B4	7	200
External Exposure	C1	0	230
	C2	3	230
	C3	5	220
	C4	7	160

From the result obtained, the slump height got from the research is high which are in the range of 160mm to 240mm. Hence, the workability of the fresh polymeric concrete is high.

MIIRHA has high surface area and it absorbs water from the polymeric concrete mixture. Therefore, workability of the fresh polymeric concrete was decreased as the percentage of MIRHA content in the polymeric concrete was increased. This was due to the absorptive character of MIRHA cellular particles.

4.2 Properties of Hardened Concrete

Several destructive tests have been conducted to determine the impact of silica fume and MIRHA addition to polymeric concrete namely tensile strength test, flexural strength test and compressive strength test. Concrete samples have been designed with two conditions, blended and non-blended source materials. Non-blended source material only has fly ash as the source material while blended source material consists of fly ash-silica fume and fly ash-MIRHA with 3%, 5% and 7% replacement.

4.2.1 Tensile Strength Test

Tensile strength test has been conducted to determine the tensile strength of concrete sample at 28 days of age. The concrete sample has been cast in 100mmx200mm cylinder in shape.

For the fly ash-silica fume concrete, tensile strength values at 28 days were observed to be varied from 1.3545 to 1.7675 MPa for hot gunny curing, 0.9472 to 2.1730 MPa for ambient curing and 1.3105 to 2.4460 MPa for external exposure curing.

For the fly ash-MIRHA concrete, tensile strength values at 28 days were observed to be varied from 1.0575 to 1.7005 MPa for hot gunny curing, 0.9472 to 1.8865 MPa for ambient curing and 1.2865 to 2.4460 MPa for external exposure curing.

From the result obtained, the tensile strength of concrete is within the range about one-tenth of the compressive strength which is about the same with conventional OPC concrete. External exposure curing gives highest tensile strength of concrete sample incorporating both MIRHA and silica fume.

Figure 4.1 and 4.2 shows the tensile strength of concrete samples incorporating silica fume and fly ash.

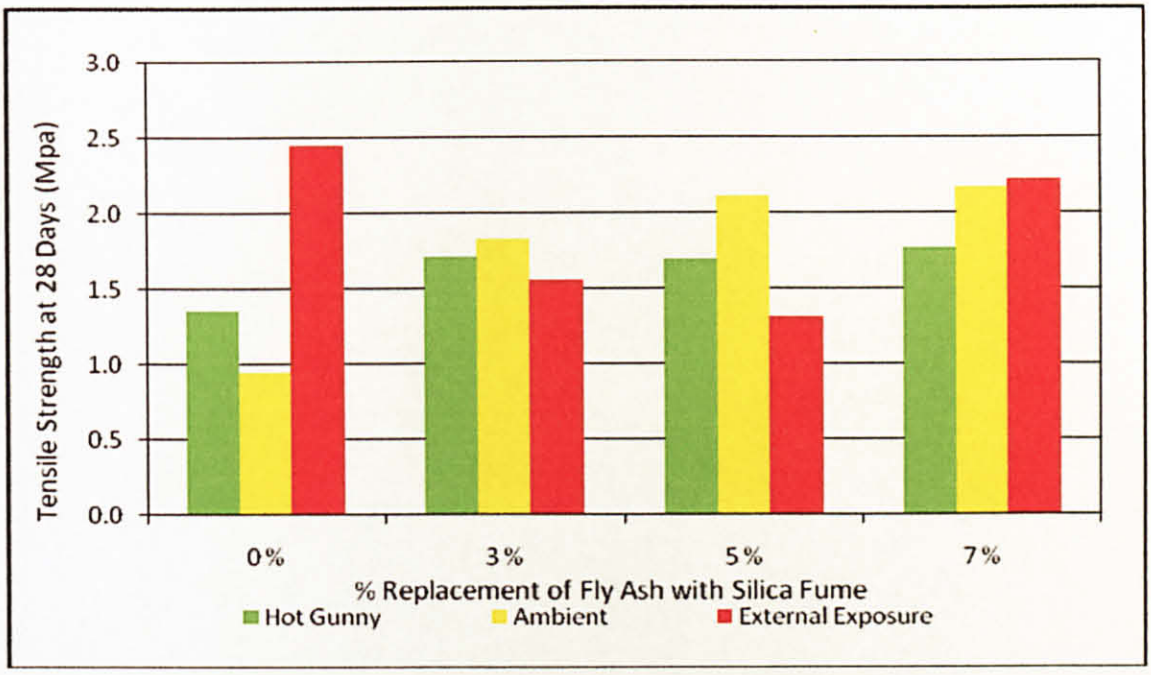

Figure 4.1: Tensile Strength (Fly Ash-Silica Fume) at 28 days

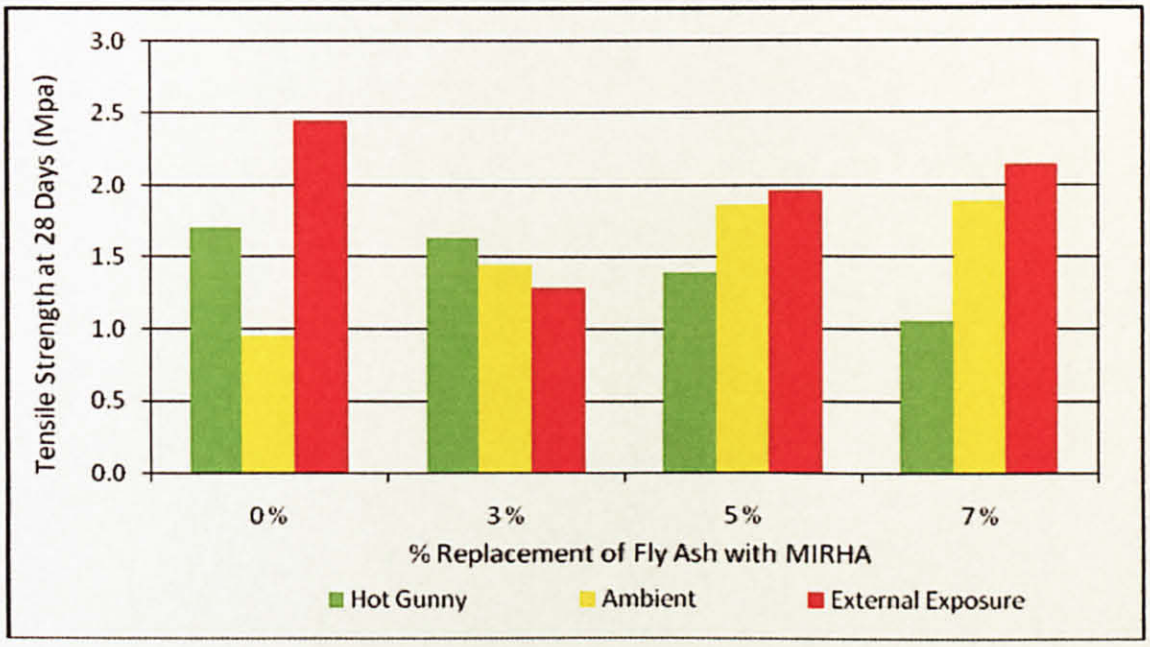

Figure 4.2: Tensile Strength (Fly Ash-MIRHA) at 28 days

4.2.2 Flexural Strength Test

Flexural strength test has been conducted to determine impact of MIRHA and silica fume on flexural strength of concrete sample at age of 28 days. The concrete beam size used in this research was 100mmx100mmx500mm.

For the fly ash-silica fume concrete, The Flexural Strength Values at 28 days were observed to be varied from 4.907to 8.354 MPa for hot gunny curing, 3.363 to 6.578 MPa for ambient curing and 4.533 to 7.914 MPa for external exposure curing.

For the fly ash-MIRHA concrete, The Flexural Strength Values at 28 days are observed to be varied from 3.249 to 5.438 MPa for hot gunny curing, 3.363 to 8.380 MPa for ambient curing and 3.890 to 6.517 MPa for external exposure curing.

Polymeric concrete incorporating silica fume in hot gunny curing gives highest flexural strength while ambient curing gives highest flexural strength on polymeric concrete incorporating MIRHA. Based on ACI commentary, tensile strength in flexure is 10-15 % of compressive strength which is slightly better for polymeric concrete.

Flexural strength values for polymeric concrete incorporating silica fume and MIRHA were illustrated in table 4.3 and 4.4.

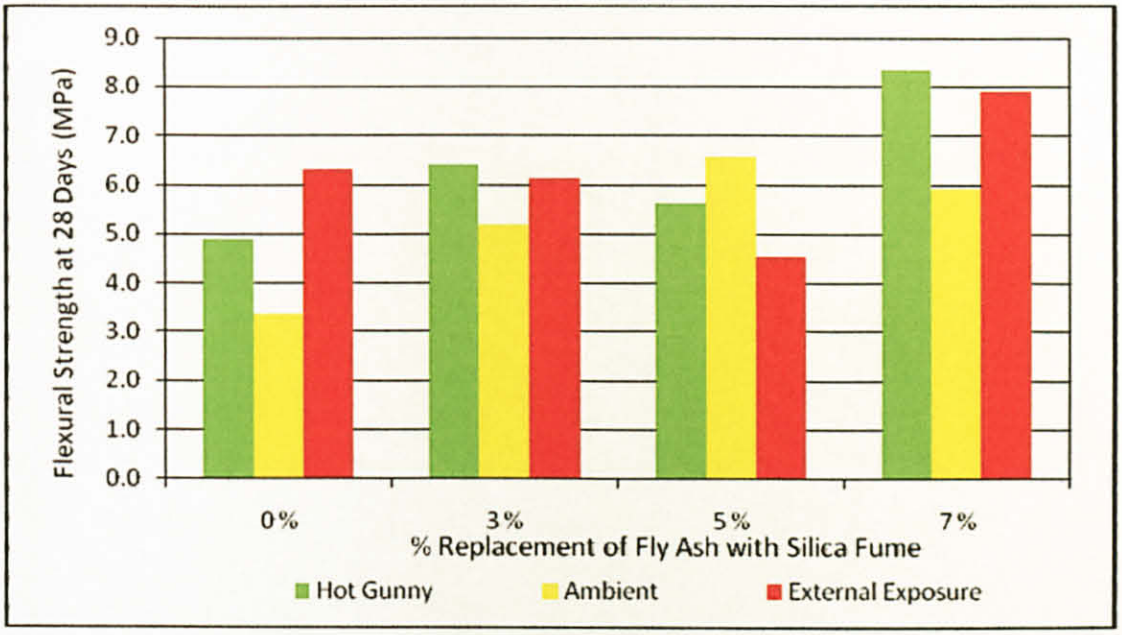

Figure 4.3: Flexural Strength (Fly Ash-Silica Fume) at 28 days

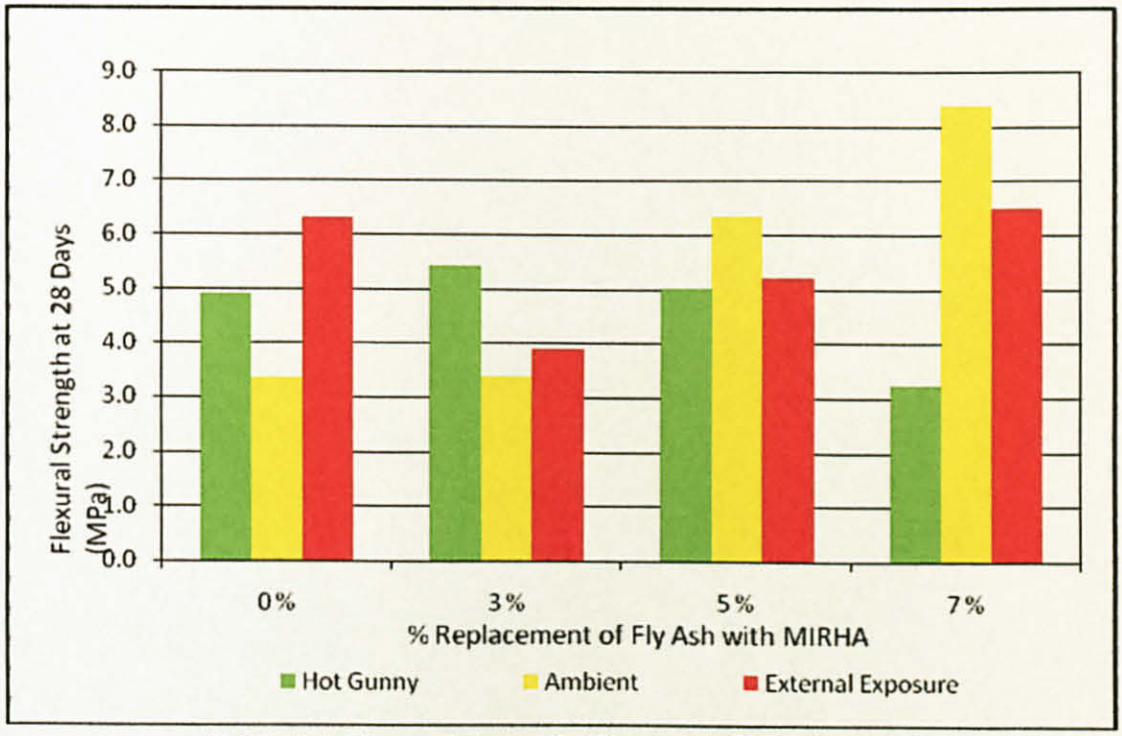

Table 4.4: Flexural Strength (Fly Ash-MIRHA) at 28 days

4.2.3 Compressive Strength Test

Compressive strength test has been conducted to analyze the impact of silica fume and MIRHA on strength of polymeric concrete. Concrete sample was casted in 100mmx100mmx100mm concrete cube. The strength development of concrete samples was measured at 3, 7 and 28 days of age.

Polymerization is a process that absorbs energy in form of heat. Therefore, activator requires heat. Unlike conventional concrete, water did not involve in the polymerization process. Therefore, too much water in curing period is not good for polymeric concrete. This has been shown by hot gunny curing as in figure 4.5 and 4.6.

MIRHA and silica fume has slow reaction in polymeric concrete. By time fly ash has already reacted with alkaline solution, it took time for polymeric concrete to react with MIRHA and silica fume.

In term of compressive strength, 7 % replacement of fly ash with silica fume is the optimum amount for hot gunny curing, 3 % is the optimum amount for ambient curing. Whereby, 5 % replacement of fly ash with MIRHA is the optimum amount for hot gunny and ambient curing.

In low temperature condition, as performed by hot gunny curing and ambient curing, the polymeric reaction rate is low. That is why blended source material could improve the concrete strength through the lower reaction rate as illustrated in Figure 4.7 and 4.8 respectively. However, addition of silica fume and MIRHA in external exposure curing does not facilitate the strength of polymeric concrete. This is because in high temperature as external exposure curing, reaction rate is high. Thus, all material reaction within fly ash and alkaline solution was happened rapidly.

Figure 4.9 and 4.10 shows the compressive strength development of concrete sample in external exposure curing.

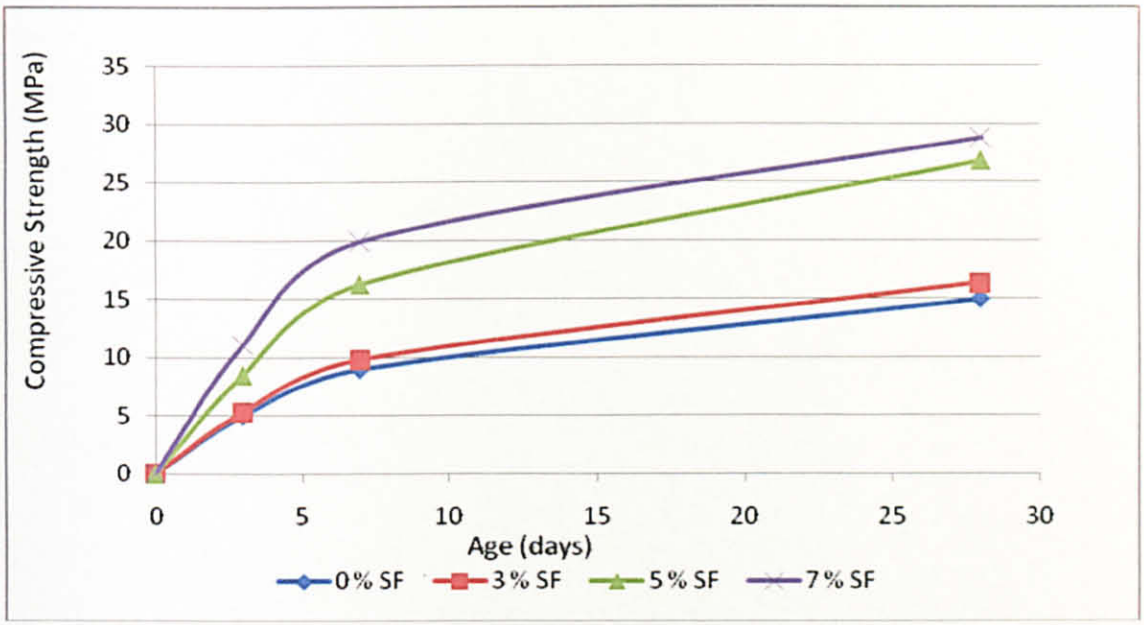

Figure 4.5: Compressive Strength of Fly Ash-Silica Fume with Hot Gunny Curing

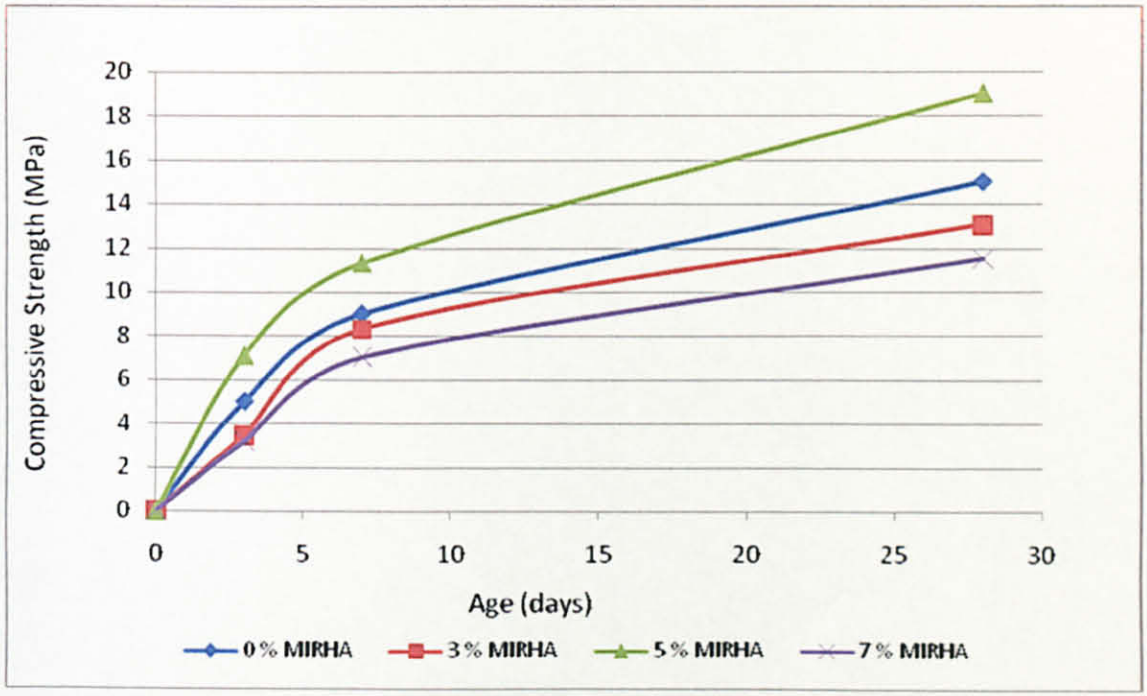

Figure 4.6: Compressive Strength of Fly Ash-MIRHA with Hot Gunny Curing

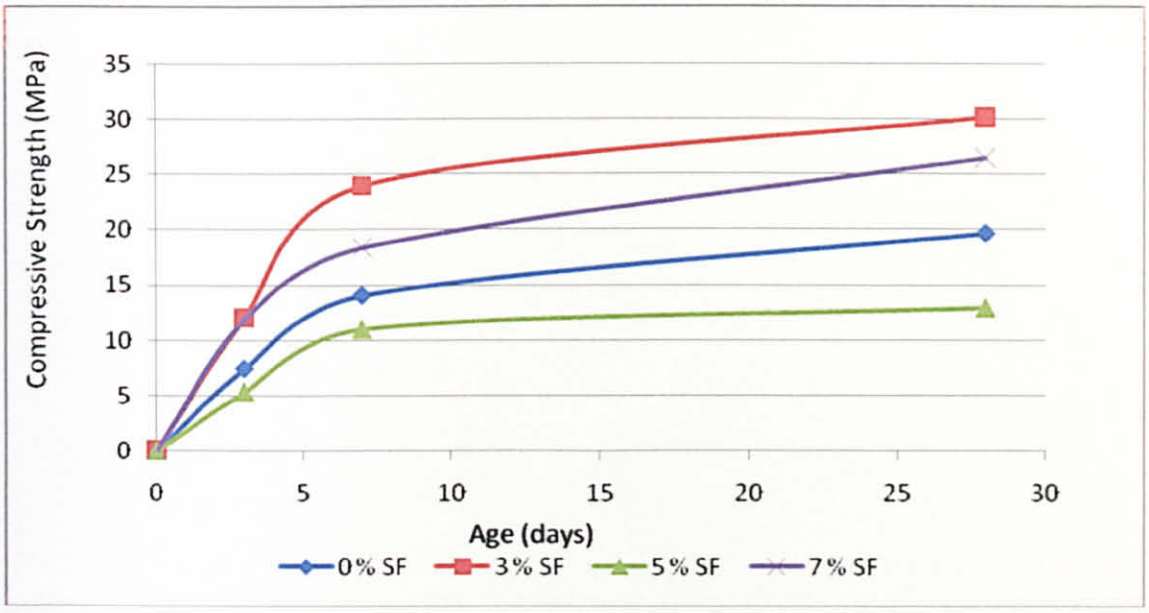

Figure 4.7: Compressive Strength of Fly-Ash Silica Fume with Ambient Curing

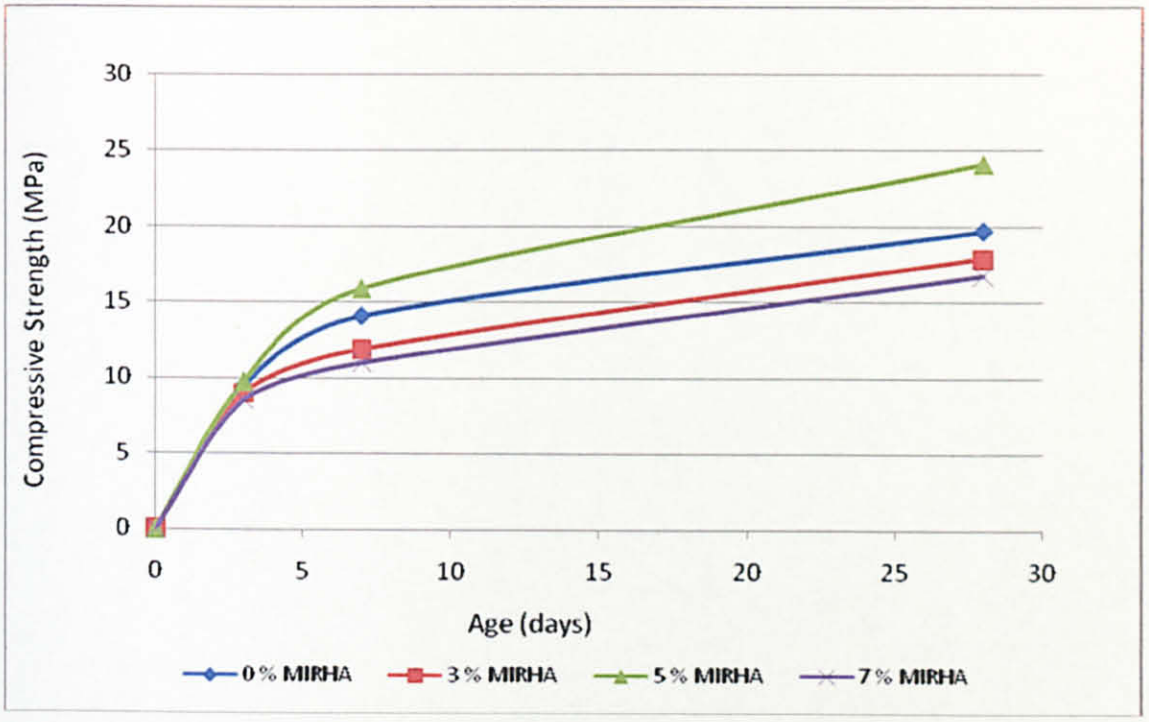

Figure 4.8: Compressive Strength of Fly Ash-MIRHA with Ambient Curing

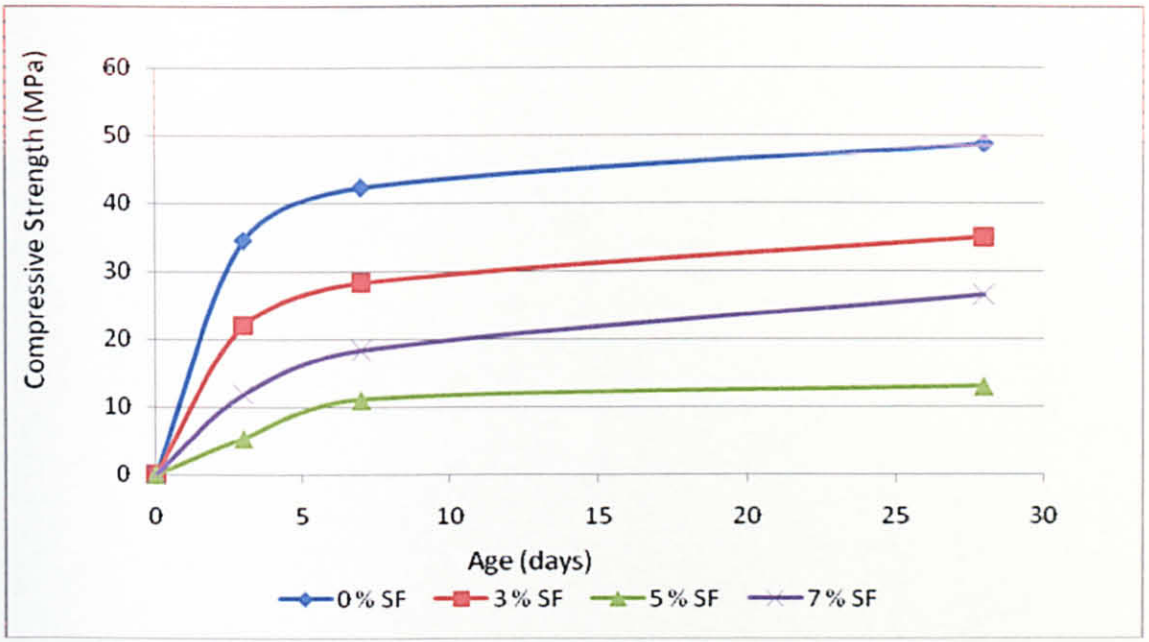

Figure 4.9: Compressive Strength of Fly Ash-Silica Fume with External Exposure Curing

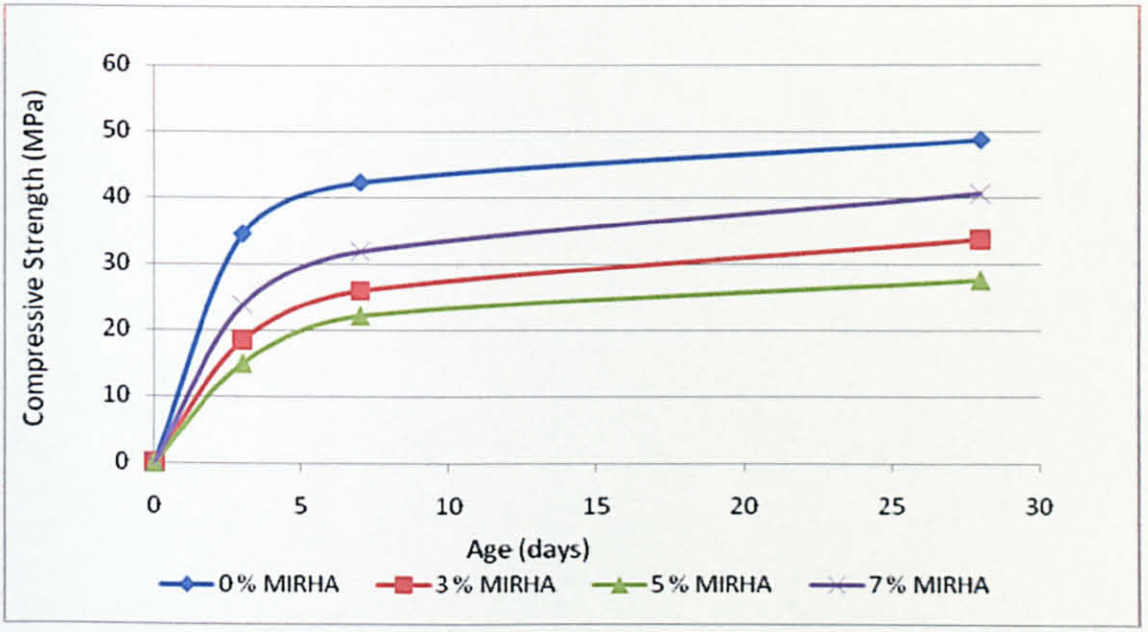

Figure 4.10: Compressive Strength of Fly Ash-MIRHA with External Exposure Curing

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This research has been carried out to determine the optimum mix proportion of polymeric concrete incorporating fly ash, MIRHA and silica fume. All in all, all the objectives have been met. The following conclusion can be drawn from the study:

- Fly ash, MIRHA and silica fume together with alkaline solution (Sodium Hydroxide, NaOH and Sodium Silicate, Na_2SiO_3) can be a good replacement of cement in concrete.

- 7 % replacement of fly ash with silica fume is the optimum amount for hot gunny curing while 3 % is the optimum amount for ambient curing. Whereby, 5 % replacement of fly ash with MIRHA is the optimum amount for hot gunny and ambient curing. This is because in low temperature, as performed by hot gunny and ambient curing, the polymeric reaction rate is low. Therefore, blended source materials could improve the concrete strength through the lower reaction rate. However, different characteristic was performed by external exposure curing. Non-blended source materials gave highest strength among all concrete samples. This is because sufficient amount of heat during daylight increase the reaction rate. Thus, all material reaction within fly ash and alkaline solution was happened rapidly. Therefore, blended source materials did not significantly improve concrete strength compared to non-blended concrete.

- External exposure is the best curing regime in cast in situ polymeric concrete. This is because polymerization needs heat from environment to initiate the reaction. External exposure curing gives the highest compressive strength for polymeric concrete incorporating fly ash-silica fume and MIRHA which are 48.70 MPa.

- The compressive strength of polymeric concrete incorporating fly ash-silica fume in hot gunny curing range from 15.00 to 28.80 MPa, in ambient curing the compressive strength range from 12.97 to 30.27 MPa while in external exposure curing the compressive strength range from 30.50 to 48.70 MPa. In the polymeric concrete incorporating fly ash-MIRHA in hot gunny curing, the compressive strength range from 11.50 to 19.01 MPa, in ambient curing the compressive strength range from 16.75 to 24.08 MPa while in external exposure curing the compressive strength range from 27.58 to 48.70 MPa.

- The tensile strength of polymeric concrete incorporating fly ash-silica fume in hot gunny curing range from 1.35 to 1.77 MPa, in ambient curing the compressive strength range from 0.95 to 2.17 MPa while in external exposure curing the compressive strength range from 1.31 to 2.45 MPa. In the polymeric concrete incorporating fly ash-MIRHA in hot gunny curing, the compressive strength range from 1.06 to 1.70 MPa, in ambient curing the compressive strength range from 0.95 to 1.89 MPa while in external exposure curing the compressive strength range from 1.29-2.45 MPa. Tensile strength of polymeric concrete is a percentage of its compressive strength which is similar to OPC concrete.

- The flexural strength of polymeric concrete incorporating fly ash-silica fume in hot gunny curing range from 4.91 to 8.35 MPa, in ambient curing the compressive strength range from 3.36 to 6.58 MPa while in external exposure curing the compressive strength range from 4.53 to 7.91 MPa. In the polymeric concrete incorporating fly ash-MIRHA in hot gunny curing, the compressive strength range from 3.25 to 5.44 MPa, in ambient curing the compressive strength

range from 3.36 to 8.38 MPa while in external exposure curing the compressive strength range from 3.89 to 6.52 MPa.

- MIRHA contributed positively to the performance of concrete.

5.2 RECOMMENDATION

From this research, it was shown that external exposure curing gives highest strength with non-blended source materials. However, concrete strength was kept on increasing with different percentage of MIRHA and silica fume. Optimum mix could be achieved beyond 7 % replacement of silica fume and MIRHA which was not included in the scope of this research. Therefore, it is recommended to further this research by utilizing percentage of fly ash replacement beyond 7% in order to get optimum mix.

CHAPTER 6

ECONOMIC BENEFITS

This chapter describes the cost of materials that has been used in this project including cost of source materials which are fly ash, MIRHA and silica fume and alkaline solution which are sodium hydroxide and sodium silicate.

6.1 COST OF PROJECT

Table 6.1 shows total weight of the materials used in making polymeric concrete in this research.

Table 6.1: Total weight of materials used in Polymeric Concrete.

Code	Fly Ash	MIRHA	Silica Fume	CA	FA	NaOH	Na_2SiO_3	Sugar
	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
A1	3.90	0.00	0.00	13.37	7.19	0.46	1.15	0.12
A2	3.78	0.12	0.00	13.37	7.19	0.46	1.15	0.12
A3	3.70	0.19	0.00	13.37	7.19	0.46	1.15	0.12
A4	3.63	0.27	0.00	13.37	7.19	0.46	1.15	0.12
AS2	3.78	0.00	0.12	13.37	7.19	0.46	1.15	0.12
AS3	3.70	0.00	0.19	13.37	7.19	0.46	1.15	0.12
AS4	3.63	0.00	0.27	13.37	7.19	0.46	1.15	0.12
B1	3.90	0.00	0.00	13.37	7.19	0.46	1.15	0.12
B2	3.78	0.12	0.00	13.37	7.19	0.46	1.15	0.12
B3	3.70	0.19	0.00	13.37	7.19	0.46	1.15	0.12
B4	3.63	0.27	0.00	13.37	7.19	0.46	1.15	0.12
BS2	3.78	0.00	0.12	13.37	7.19	0.46	1.15	0.12
BS3	3.70	0.00	0.19	13.37	7.19	0.46	1.15	0.12
BS4	3.63	0.00	0.27	13.37	7.19	0.46	1.15	0.12
C1	3.90	0.00	0.00	13.37	7.19	0.46	1.15	0.12
C2	3.78	0.12	0.00	13.37	7.19	0.46	1.15	0.12
C3	3.70	0.19	0.00	13.37	7.19	0.46	1.15	0.12
C4	3.63	0.27	0.00	13.37	7.19	0.46	1.15	0.12
CS2	3.78	0.00	0.12	13.37	7.19	0.46	1.15	0.12
CS3	3.70	0.00	0.19	13.37	7.19	0.46	1.15	0.12
CS4	3.63	0.00	0.27	13.37	7.19	0.46	1.15	0.12

Costs of materials are calculated based on total weight of the materials used. Cost of polymeric concrete is given in the table 6.2.

Table 6.2: Cost of Polymeric Concrete

Material	**Quantity**	**Cost** Cost of Polymeric Concrete	**Amount**
	(kg)	**(RM)**	**(RM)**
Fly Ash	78.36	-	-
MIRHA	1.74	3.60/kg	6.26
Silica Fume	1.74	4.50/kg	7.83
NaOH	9.66	0.75/kg	7.25
Na_2SiO_3	24.15	1.20/kg	28.98
TOTAL			50.32

Portland cement is cheaper because it is mass produced, however several decades from now the availability of raw material for cement production especially limestone will deplete. It is important for us to use alternative binders such as fly ash, MIRHA and silica fume in order to replace the usage of Portland cement concrete as construction materials. Therefore, at that time geopolymer concrete will be a very important part of construction industry. As we know, fly ash is abundantly available nowadays as a by product. NaOH pellets cost RM 0.75/kg while Na_2SiO_3 is RM 1.20/kg at chemical store. The price of NaOH can be cheaper if we directly buy from the factory. For example, Na_2SiO_3 in store cost around RM 100/kg, but in factory only RM 1.2/kg. So in here we can see the price differences when a material is mass produced. The price of materials if it is mass produced. Thus, we can reduce the cost for a project. Furthermore, several researches has showed that if geopolymer cement is mass produced, the energy consumed for production in calcination, crushing, etc is 3.5 times lower than portland cement where geopolymer concrete consumed 990 MJ/tonne, while portland cement consumed 3430 MJ/tonne. 1 tonne geopolymer cement also emits only 0.184 tonnes CO_2, meanwhile 1 ton OPC generate 1 ton CO_2, so it is 6 times lower than OPC.

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APPENDIX A

Table A.1: List of countries by cement production in 2005 mostly based on indexmundi accessed in September 2008. (Source: Indexmundi)

Rank by sovereign state	Country/Region	Cement Production (tones)
-	World	2,310,000,000
1	China	1,038,300,000
2	India	145,000,000
3	United States	100,903,000
4	Japan	69,629,000
5	South Korea	51,391,000
6	Spain	50,347,000
7	Russia	48,700,000
8	Italy	46,404,000
9	Turkey	42,787,000
10	Thailand	37,872,000

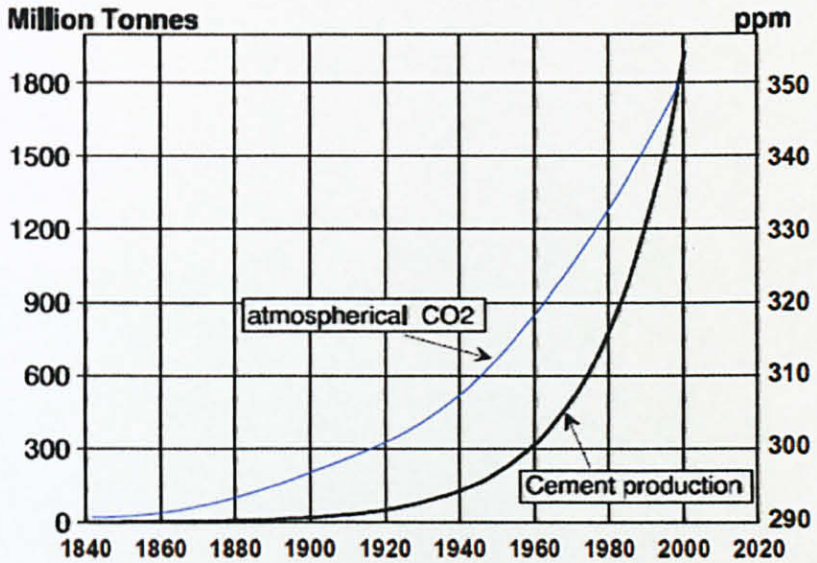


Figure A.1: Atmospheric CO_2 concentration (ppm) and world Portland cement production (million tones) for the period 1840-2000. (Source: IPCC and Cembureau)

Table A.2: Estimation of cost increase or decrease for construction materials assuming CO_2 taxes on energy alone and on energy+chemical- CO_2 emission

material	CO_2 tax energy alone	CO_2 tax energy+chemical CO_2
Portland cement concrete	+ 20%	+ 50%
Blended Portland cement concrete		
50% Portland/50% by-products	+ 20%	+ 35%
steel	+ 20%	+ 30%
wood	0%	0 to - 30%
Geopolymer cement concrete	+ 10%	+ 15%

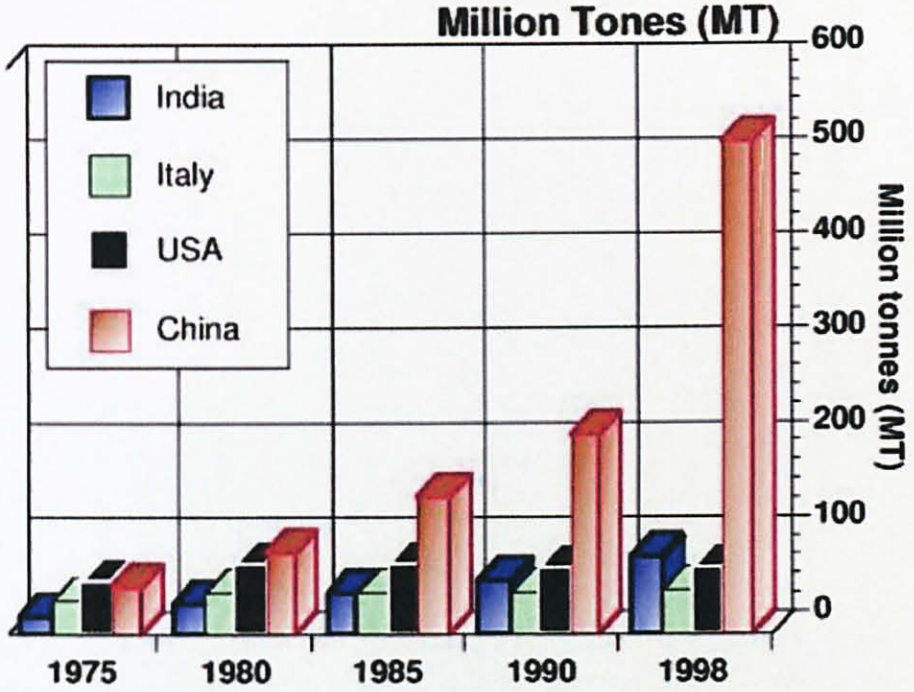


Figure A.2: Annual cement production for China, India, Italy, USA in million tones (MT.) (Source: Cembureau)

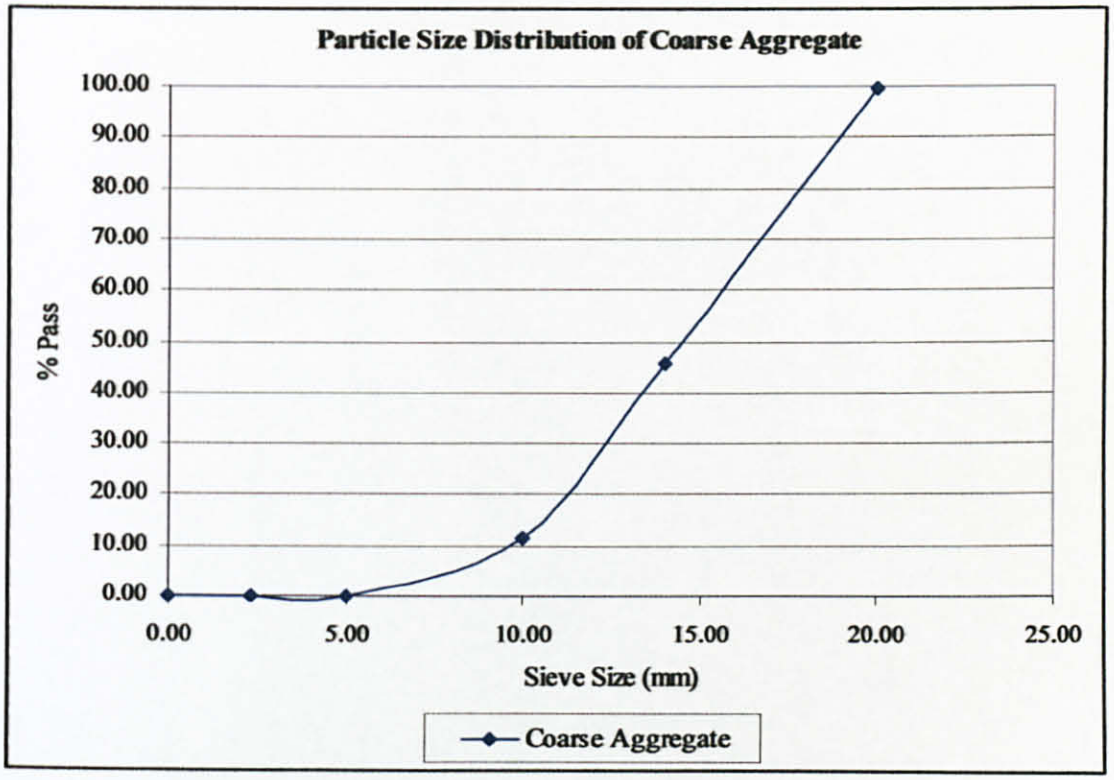
APPENDIX B

SIEVE ANALYSIS OF COARSE AND FINE AGGREGATES

Sieve Analysis Results of Coarse Aggregate

Sieve Size (mm)	Mass Retained (g)	% Mass Retained	Σ % Mass Retained	% Finer
20.00	11	0.50	0.50	99.50
14.00	1078	54.00	54.50	45.50
10.00	682	34.13	88.63	11.37
5.00	224	11.21	99.84	0.16
2.36	1	0.05	99.89	0.11
0	2	0.10	99.99	0.01

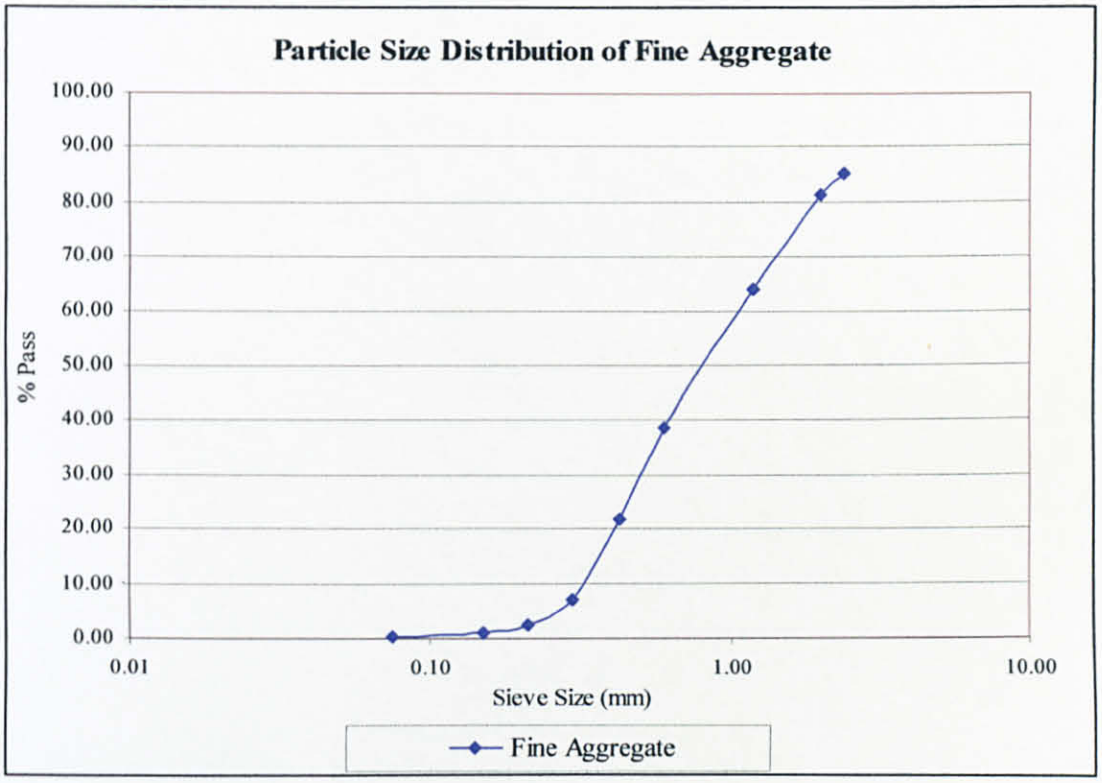
Particle Size Distribution Chart of Coarse Aggregate



Sieve Analysis Results of Fine Aggregate

Sieve Size (mm)	Mass Retained (g)	% Mass Retained	Σ % Mass Retained	% Finer
2.36	74	14.80	14.8	85.20
2.00	20	4.00	18.80	81.20
1.18	86	17.20	36.00	64.00
0.60	127	25.40	61.40	38.60
0.43	84	16.80	78.20	21.80
0.30	74	14.80	93.00	7.00
0.21	22	4.40	97.40	2.60
0.15	8	1.60	99.00	1.00
0.08	4	0.80	99.80	0.20
0.00	1	0.20	100.00	0.00

Particle Size Distribution Chart of Coarse Aggregate



APPENDIX C

TENSILE STRENTH TEST RESULT

Table C.1: Tensile Strength Test (Fly Ash-Silica Fume) at 28 days

Code	Tensile (MPa)	Compressive (MPa)	% Tensile to Compressive (%)	Average	Curing Regime
A1	1.3545	15.00	9.03	7.63	Hot Gunny
AS2	1.7140	16.37	10.47		
AS3	1.6930	26.90	6.29		
AS4	1.7675	28.80	6.14		
B1	0.9472	19.73	4.80	10.18	Ambient
BS2	1.8330	30.27	6.06		
BS3	2.1115	12.97	16.28		
BS4	2.1730	26.50	8.20		
C1	2.4460	48.70	5.02	4.66	External Exposure
CS2	1.5570	35.00	4.45		
CS3	1.3105	30.50	4.30		
CS4	2.2195	42.30	5.25		

Table C.2: Tensile Strength Test (Fly Ash-MIRHA) at 28 days

Code	Tensile (MPa)	Compressive (MPa)	% Tensile to Compressive (%)	Average	Curing Regime
A1	1.7005	15.00	10.97	9.72	Hot Gunny
A2	1.6245	13.07	12.66		
A3	1.3885	19.01	7.30		
A4	1.0575	11.50	9.20		
B1	0.9472	19.73	4.80	8.89	Ambient
B2	1.4460	17.92	8.07		
B3	1.8565	24.08	7.34		
B4	1.8865	16.75	11.26		
C1	2.4460	48.7	5.02	5.21	External Exposure
C2	1.2865	33.8	3.65		
C3	1.9520	27.58	6.80		
C4	2.1430	40.70	5.18		

APPENDIX D

FLEXURAL STRENTH TEST RESULT

Table D.1: Flexural Strength Test (Fly Ash-Silica Fume) at 28 days

Code	Flexural (MPa)	Compressive (MPa)	% Flexural to Compressive (%)	Average	Curing Regime
A1	4.907	15.00	31.66	29.67	Hot Gunny
AS2	6.414	16.37	39.45		
AS3	5.644	26.90	20.27		
AS4	8.354	28.80	29.30		
B1	3.363	19.73	17.05	30.07	Ambient
BS2	5.182	30.27	17.12		
BS3	6.578	12.97	50.72		
BS4	5.927	26.50	22.37		
C1	6.323	48.70	12.94	16.63	External Exposure
CS2	6.127	35.00	16.72		
CS3	4.533	30.50	14.45		
CS4	7.914	42.30	18.72		

Table D.2: Flexural Strength Test (Fly Ash-MIRHA) at 28 days

Code	Flexural (MPa)	Compressive (MPa)	% Flexural to Compressive (%)	Average	Curing Regime
A1	4.907	15.00	31.66	32.35	Hot Gunny
A2	5.438	13.07	42.39		
A3	5.020	19.01	26.41		
A4	3.249	11.50	28.25		
B1	3.363	19.73	17.05	31.34	Ambient
B2	3.395	17.92	18.95		
B3	6.336	24.08	25.04		
B4	8.380	16.75	50.03		
C1	6.323	48.70	12.94	14.98	External Exposure
C2	3.890	33.80	11.05		
C3	5.205	27.58	18.14		
C4	6.517	40.70	15.76		

APPENDIX E

COMPRESSIVE STRENTH TEST RESULT

Table E.1: Compressive Strength Test (Fly Ash-Silica Fume)

	Compressive Strength (MPa)	Compressive Strength (MPa)	Compressive Strength (MPa)
Code	**3 days**	**7 days**	**28 days**
A1	5.00	9.00	15.00
AS2	5.30	9.81	16.37
AS3	8.50	16.30	26.90
AS4	11.06	19.90	28.80
B1	7.46	14.11	19.73
BS2	12.07	24.04	30.27
BS3	5.35	11.04	12.97
BS4	11.90	18.39	26.50
C1	34.50	42.30	48.70
CS2	22.00	28.30	35.00
CS3	19.10	25.10	30.50
CS4	31.90	37.00	42.30

Table E.2: Compressive Strength Test (Fly Ash-MIRHA)

	Compressive Strength (MPa)	Compressive Strength (MPa)	Compressive Strength (MPa)
Code	**3 days**	**7 days**	**28 days**
A1	5.00	9.00	15.00
A2	3.46	8.31	13.07
A3	7.11	11.31	19.01
A4	3.19	7.01	11.50
B1	9.50	14.11	19.73
B2	9.00	11.90	17.92
B3	9.77	15.89	24.08
B4	8.55	11.00	16.75
C1	34.50	42.30	48.70
C2	18.50	25.98	33.80
C3	14.98	22.13	27.58
C4	23.80	31.90	40.70